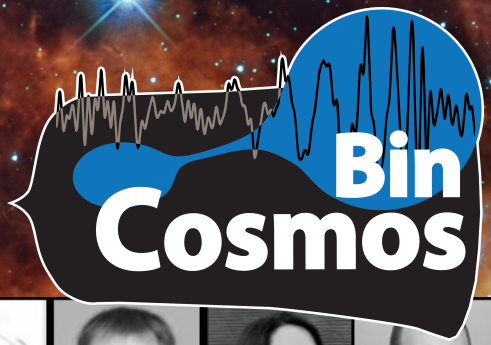
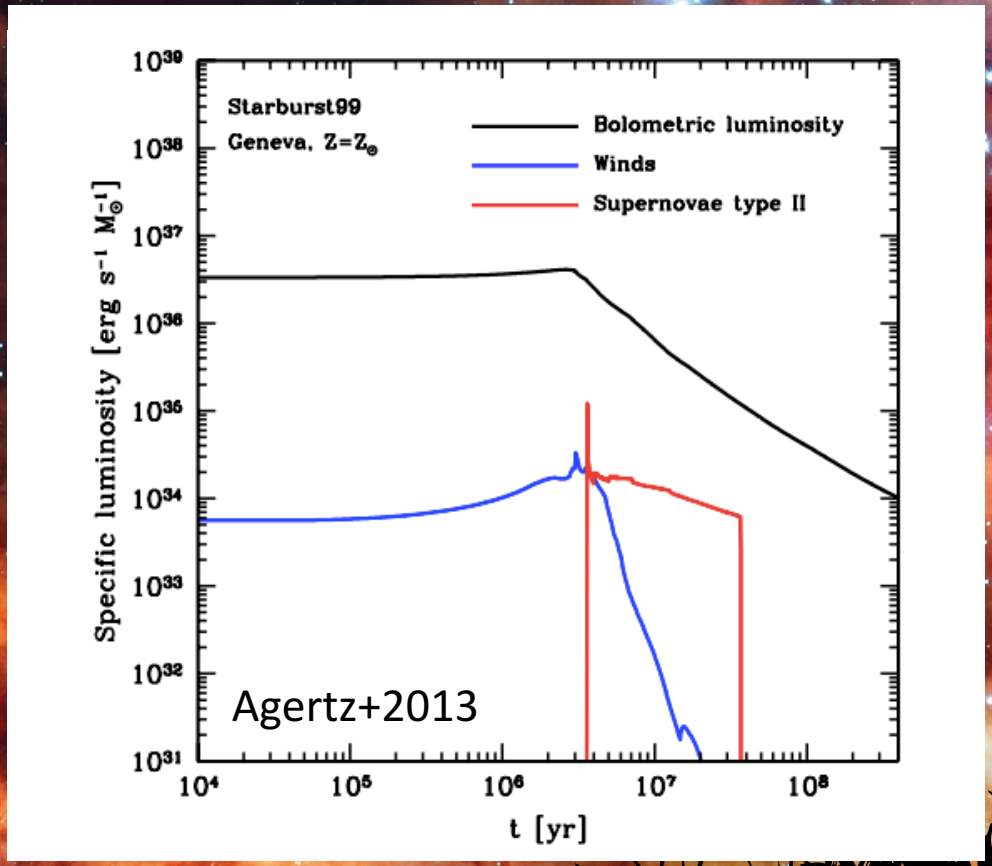
Massive Stars as Galactic Engines

Potsdam Thinkshop on feedback in galaxy formation



Selma E. de Mink

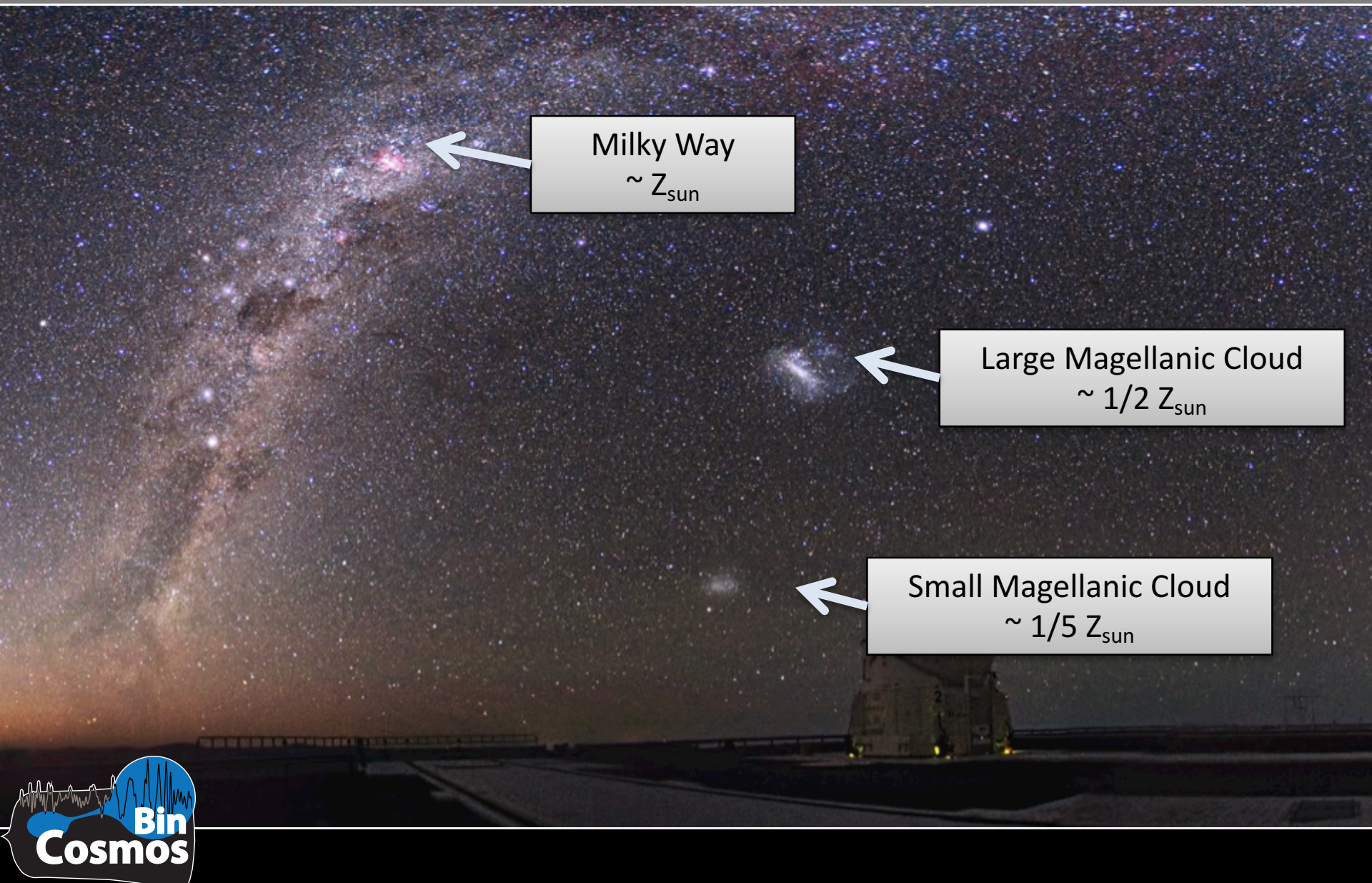
University of Amsterdam



TOWARD A COMPLETE ACCOUNTING OF ENERGY AND MOMENTUM FROM STELLAR FEEDBACK IN GALAXY FORMATION SIMULATIONS

Credit background NASA Paresce., Design E. Butink

A massive star Safari



Bin Cosmos

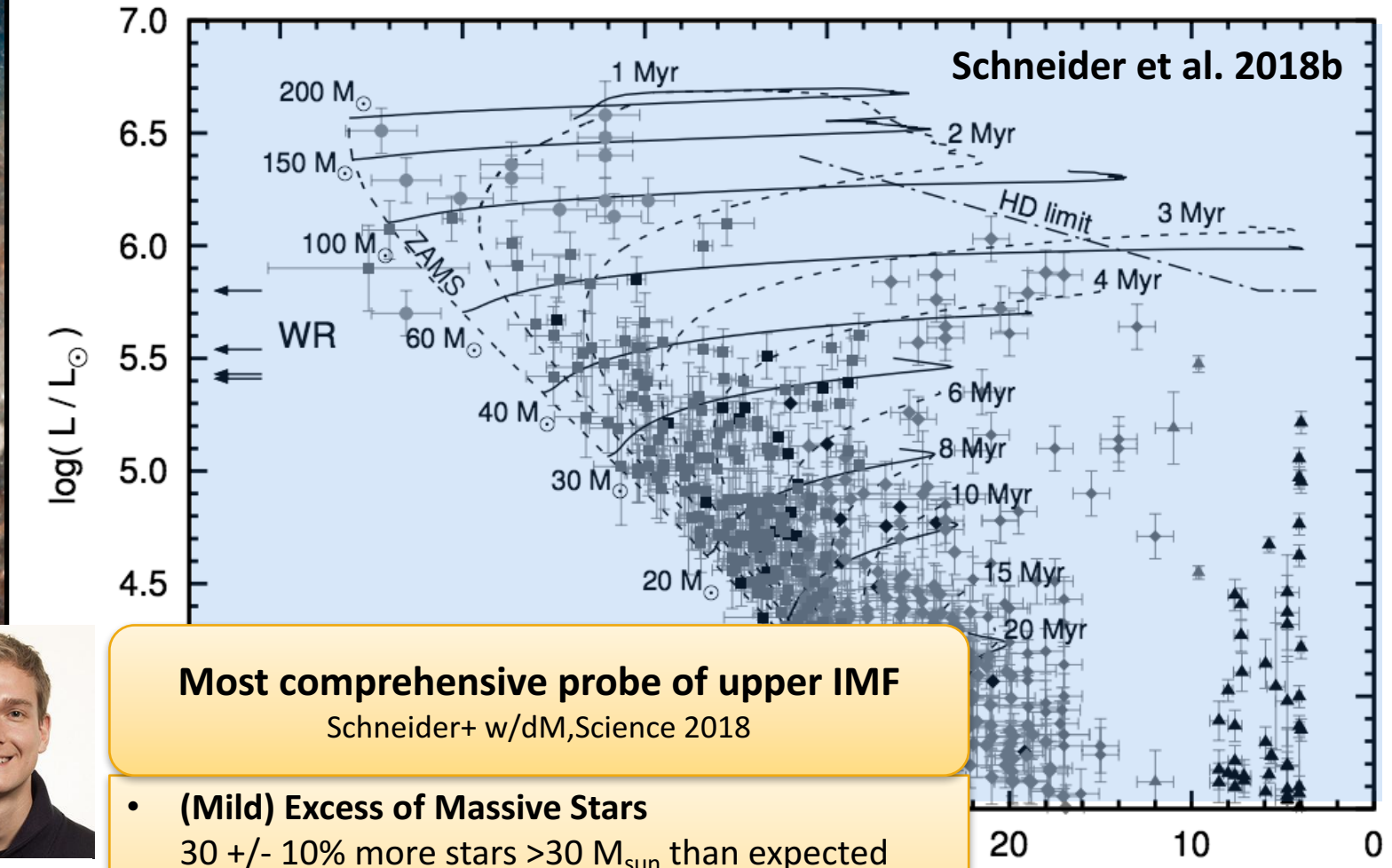
30 Doradus

Bin Cosmos

VLT-FLAMES Tarantula Survey

Evans et al. 2011

multi-epoch optical spectra of over 900 massive stars



Fabian Schneider

Most comprehensive probe of upper IMF

Schneider+ w/dM,Science 2018

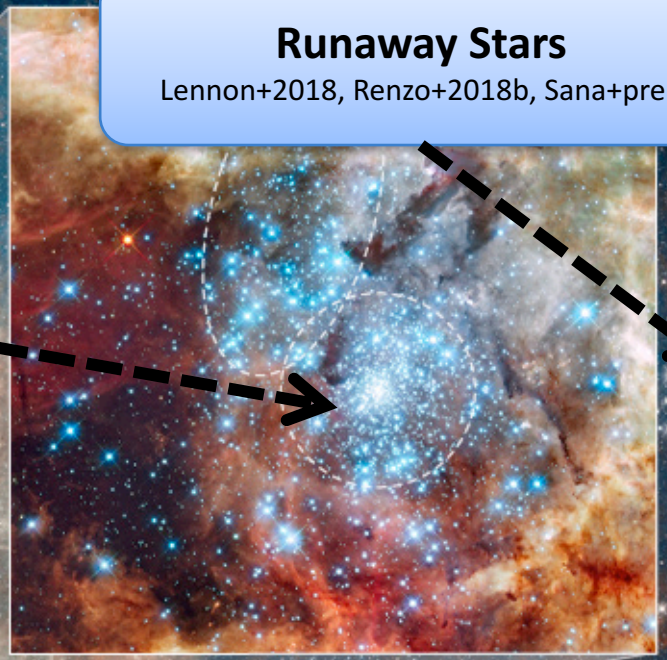
- **(Mild) Excess of Massive Stars**
  30 +/- 10% more stars >30 M_{sun} than expected
- **Flatter IMF but consistent with Salpeter:**
  $\alpha = 1.9\ ^{+0.37}_{-0.26}$ ($\alpha_{Salpeter} = 2.35$)

“Monster Stars” > 100 - 250 M_{sun}

e.g Crowther+ w/dM 2015

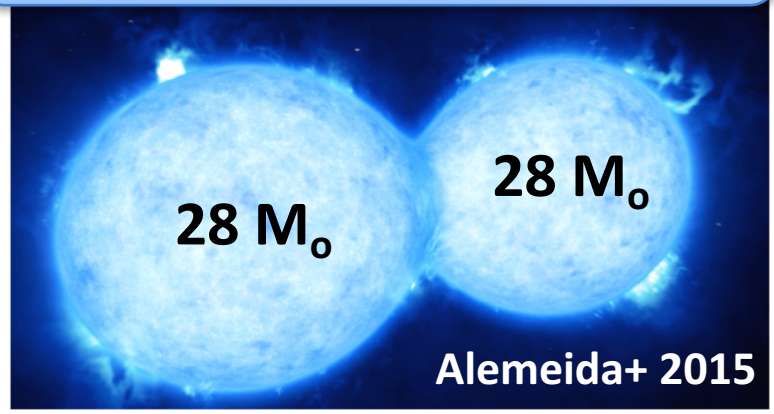
Runaway Stars

Lennon+2018, Renzo+2018b, Sana+prep



Binaries binaries binaries!

Sana+2013, Almeida+2016

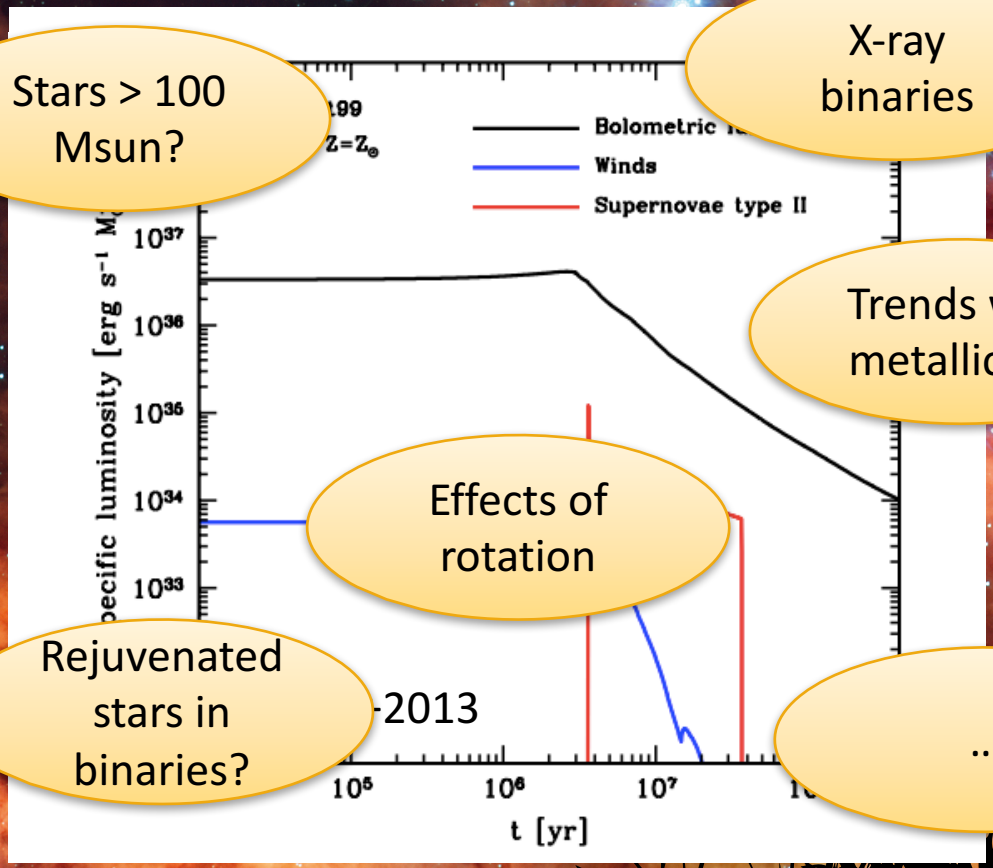


Spinning stars

Dufton+w/dM+11,13, Ramirez-agudelo++w/dM13,15

BinCosmos

How complete is this picture?



Stars > 100 Msun?

X-ray binaries

Stripped stars in binaries?

Trends with metallicity?

Walkaway / runaways

Effects of rotation

Rejuvenated stars in binaries?

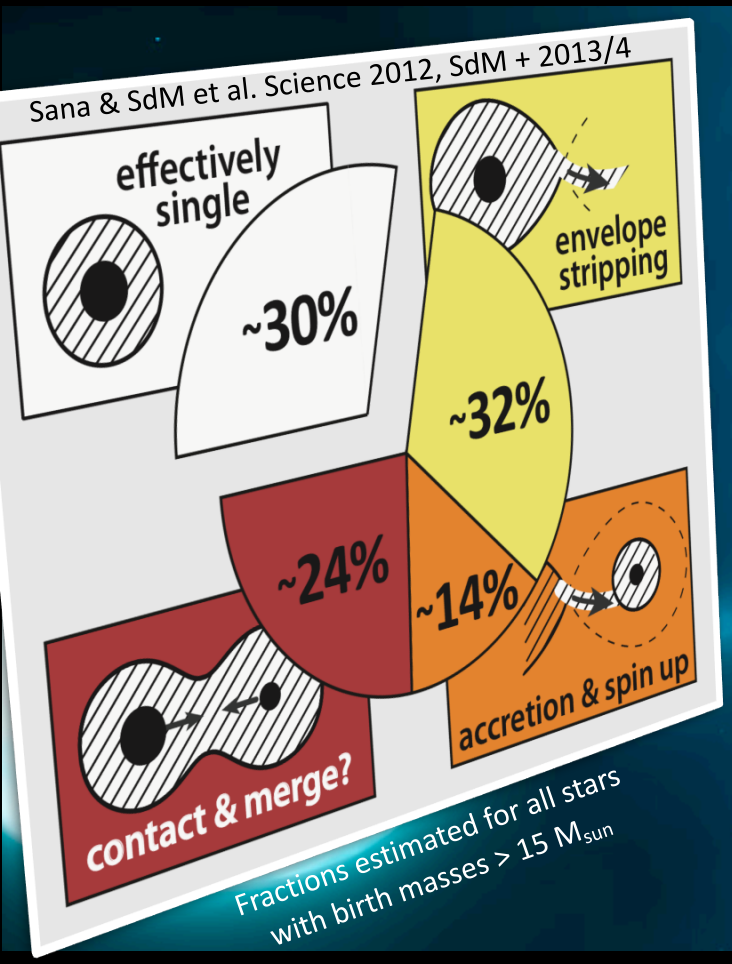
...

Triples

Credit background NASA Paresce., Design E. Bubnk

Part I

This is not exotic

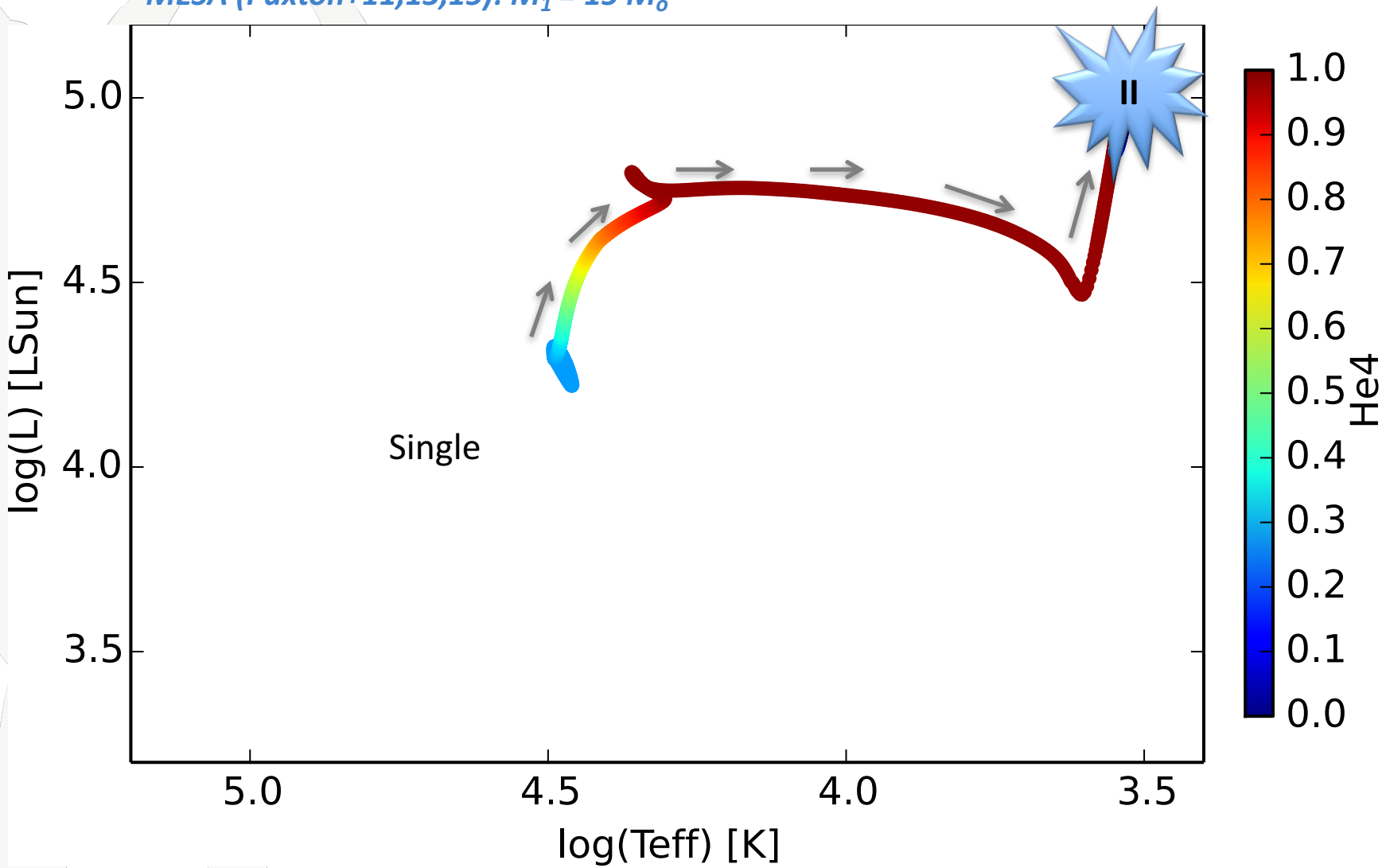


cf. Abt+78, Kobulnicky+Fryer07, Mason+09,
Chini+12, Sana,SdM+12, Sana,deKoter,SdM+13, Kobulnicky+14,
Dunstall+w/SdM15, Moe+16, Almeida+w/SdM17, ... Moe+18

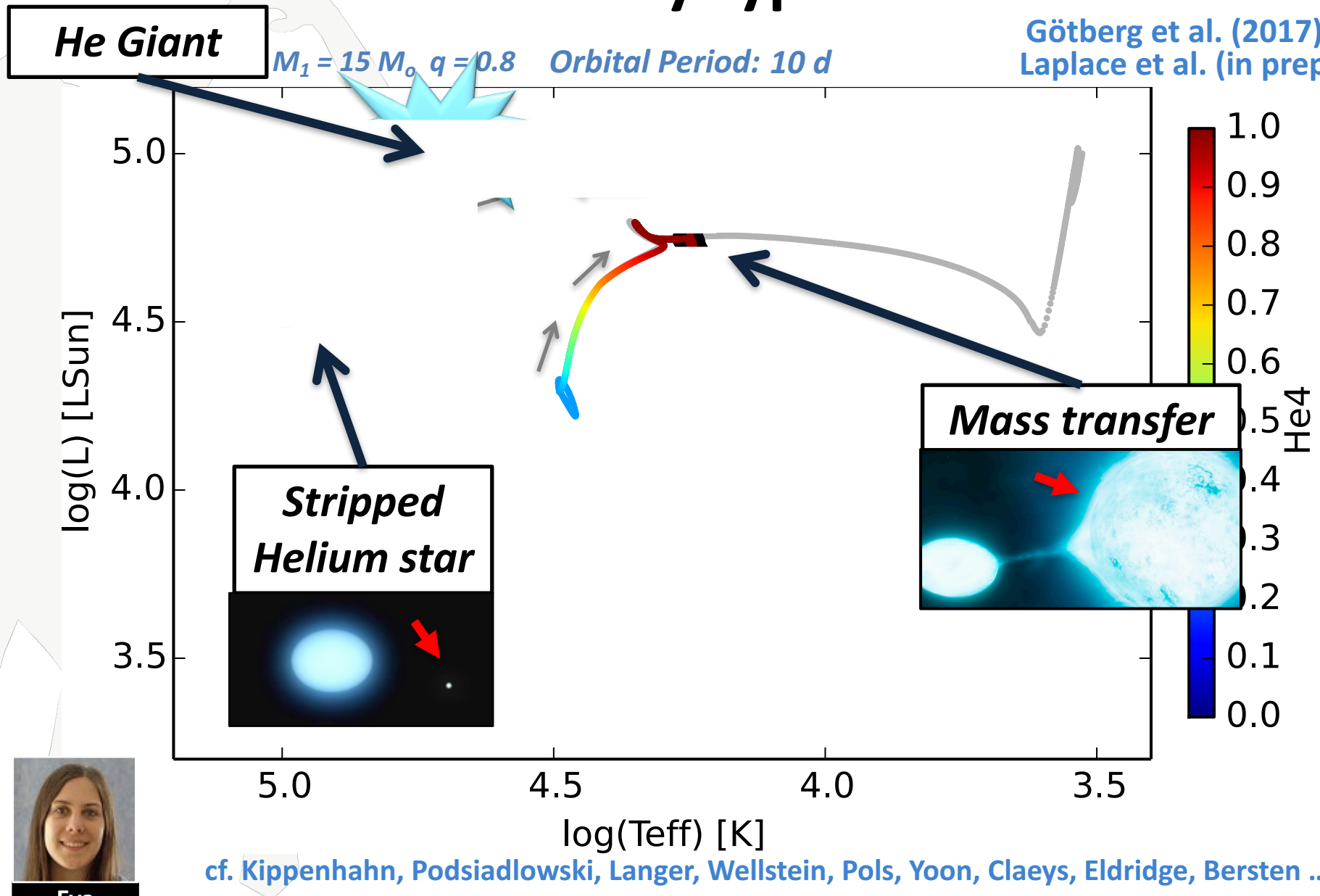
Bin Cosmos

Evolution of a single star

MESA (Paxton+11,13,15): M_1 = 15 M_o



Evolution of a very typical donor star



Eva Laplace

cf. Kippenhahn, Podsiadlowski, Langer, Wellstein, Pols, Yoon, Claeys, Eldridge, Bersten ….

Animation of the life of a typical massive Star

www.eso.org

Bin Cosmos

Animation: ESO: Calçada/Kornmesser/de Mink

Part II
Implications

Applications / Implications

1. Ionizing photons

Götberg et al. 2017, 2018 & to be subm.

Ylva Götberg

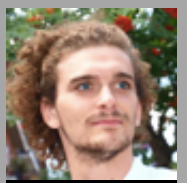
2. Late Supernovae

Zapartas et al. 2017, 2018 & to be subm

Manos Zapartas

3. Walkaways & Runaways

Renzo et al. 2018a, b



Mathieu Renzo

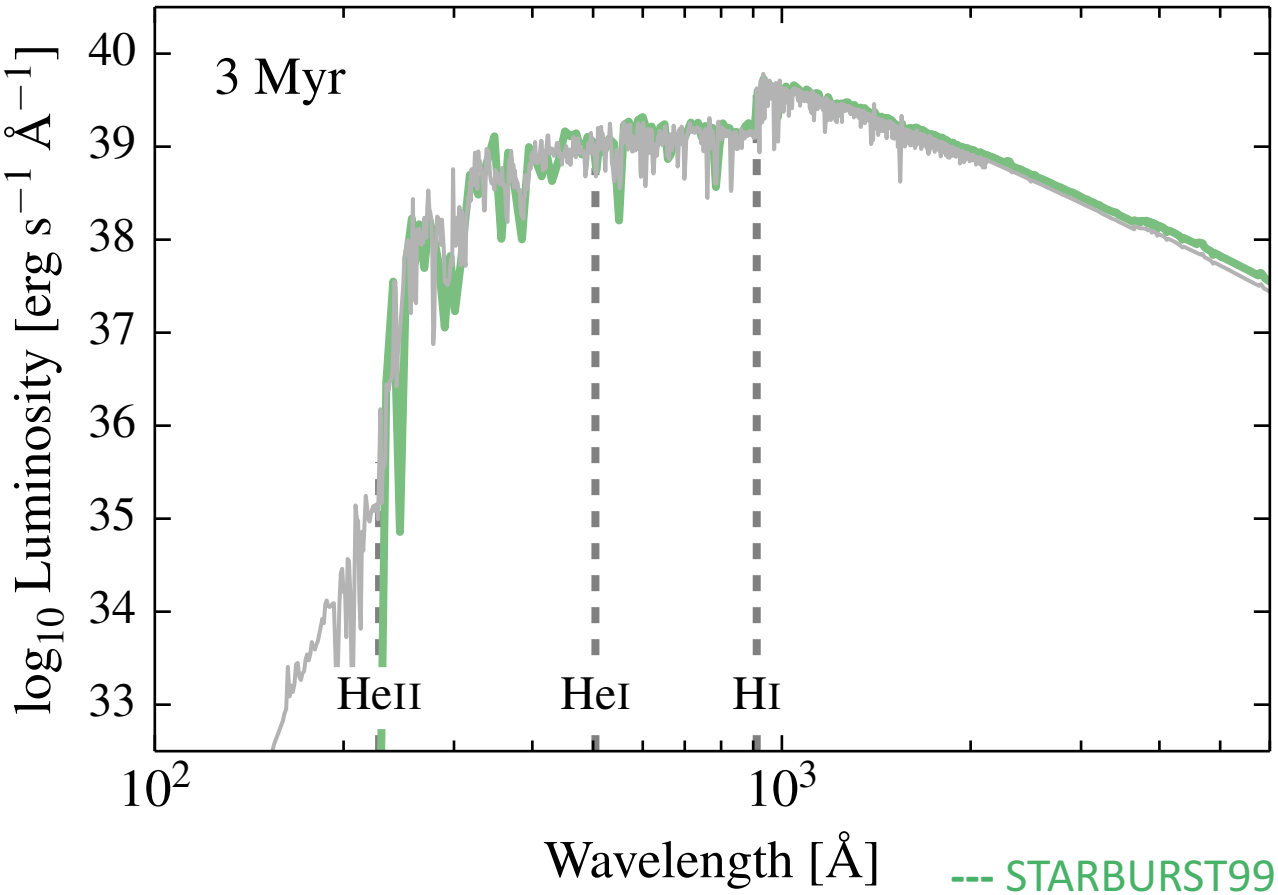
New grids of atmosphere models for stripped stars

Götberg, de Mink & Groh (2017)
Götberg et al. (2018)

Ylva Götberg

Implications for integrated spectrum of a Stellar Population

Götberg, dM, Leitherer et al. (to be subm.)



--- STARBURST99 (Leitherer+)

--- BPASS (JJ Eldrigde+)

Ylva Götberg

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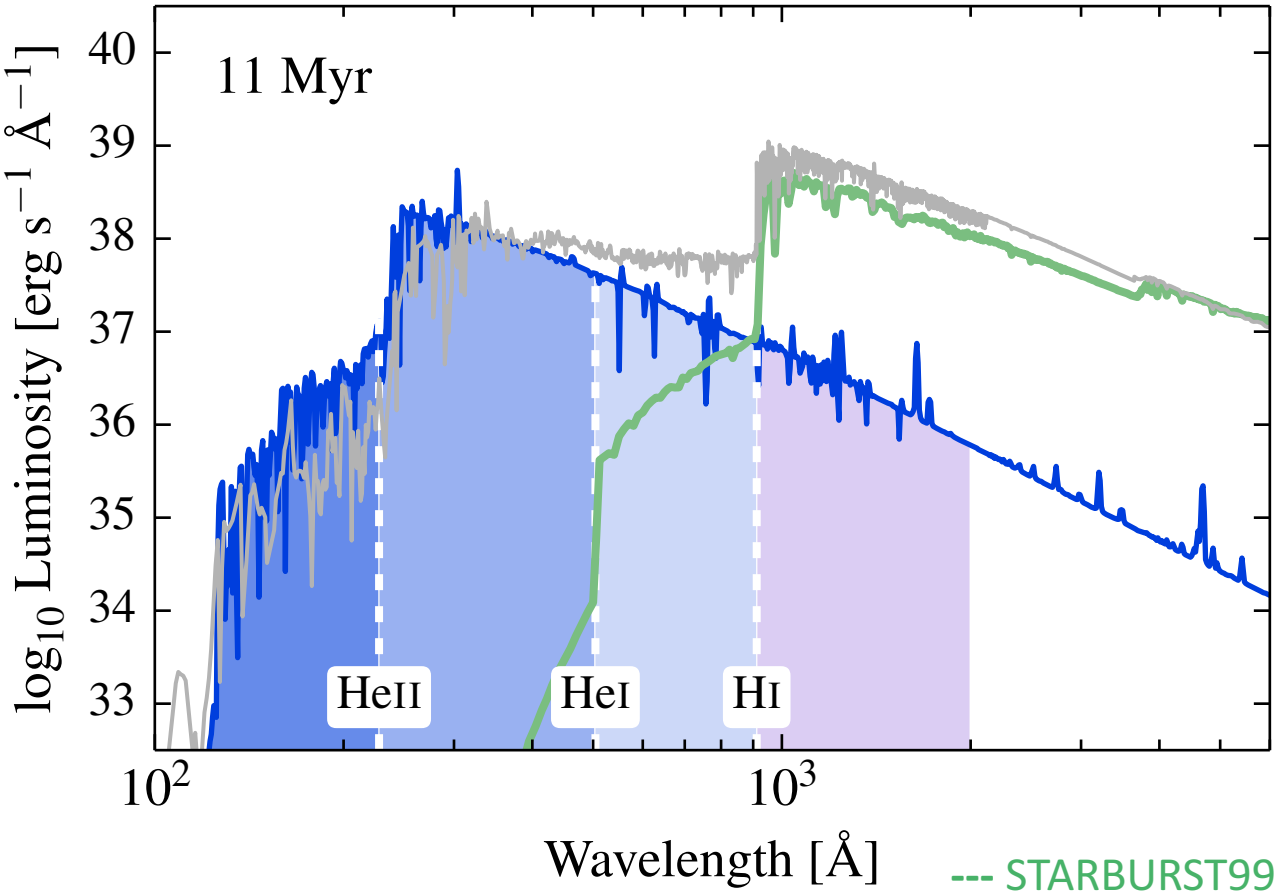

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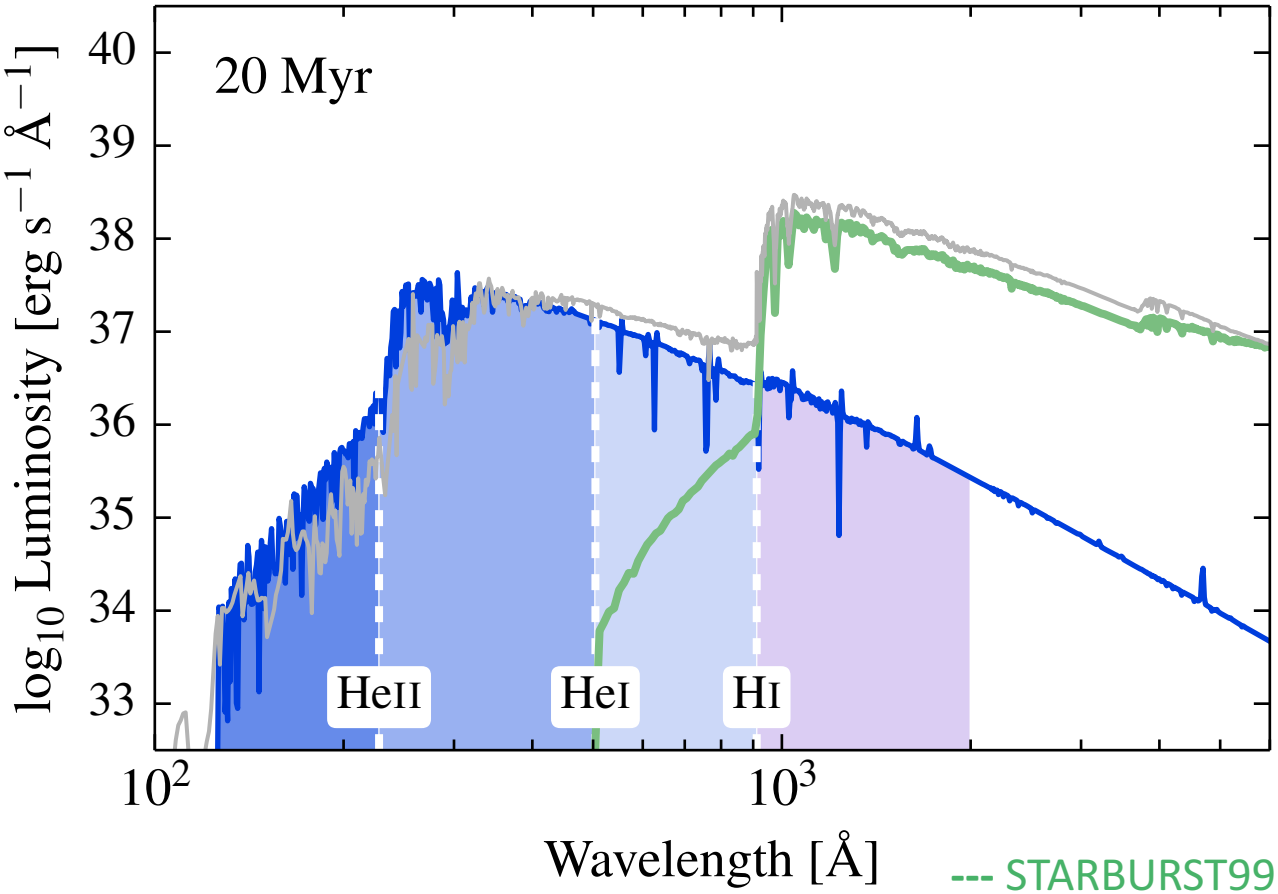

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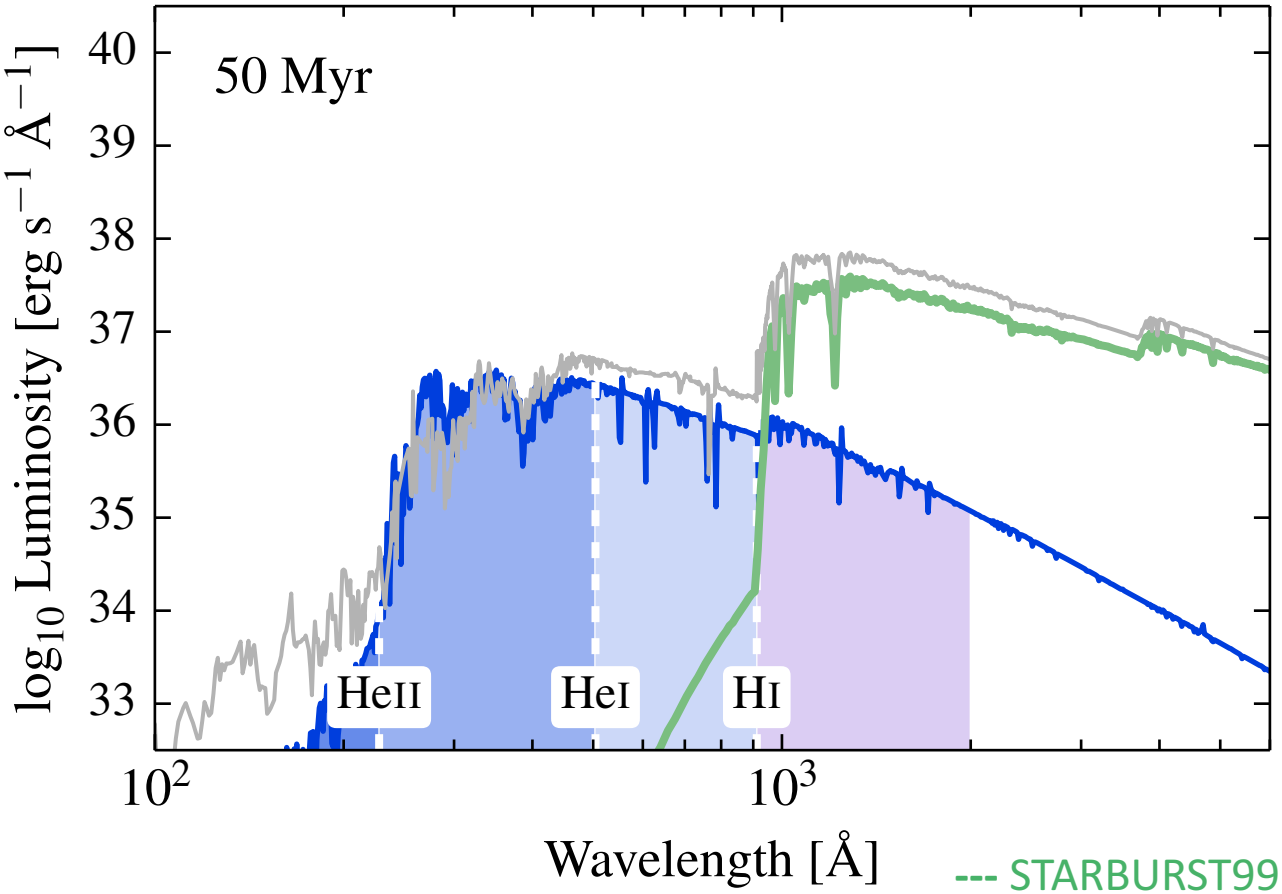

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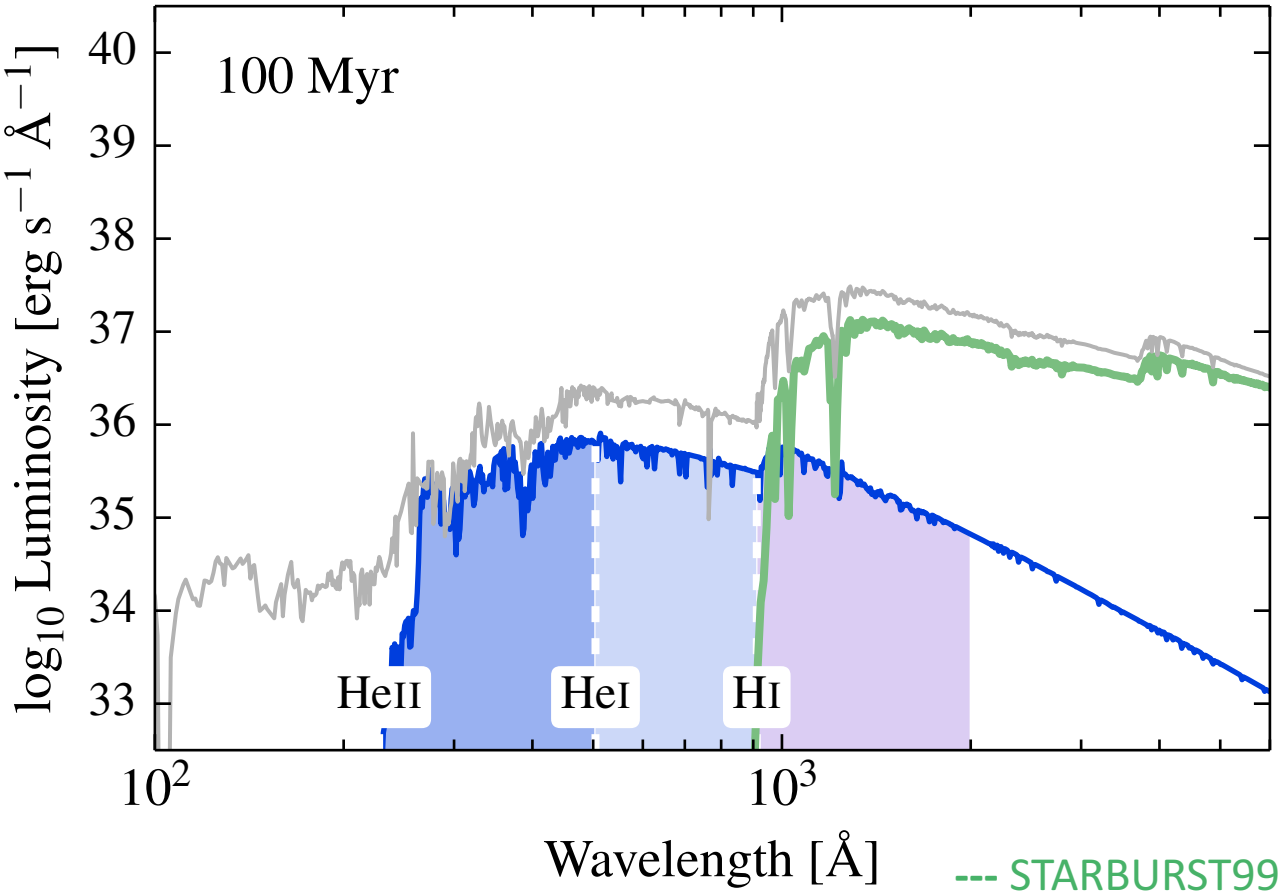

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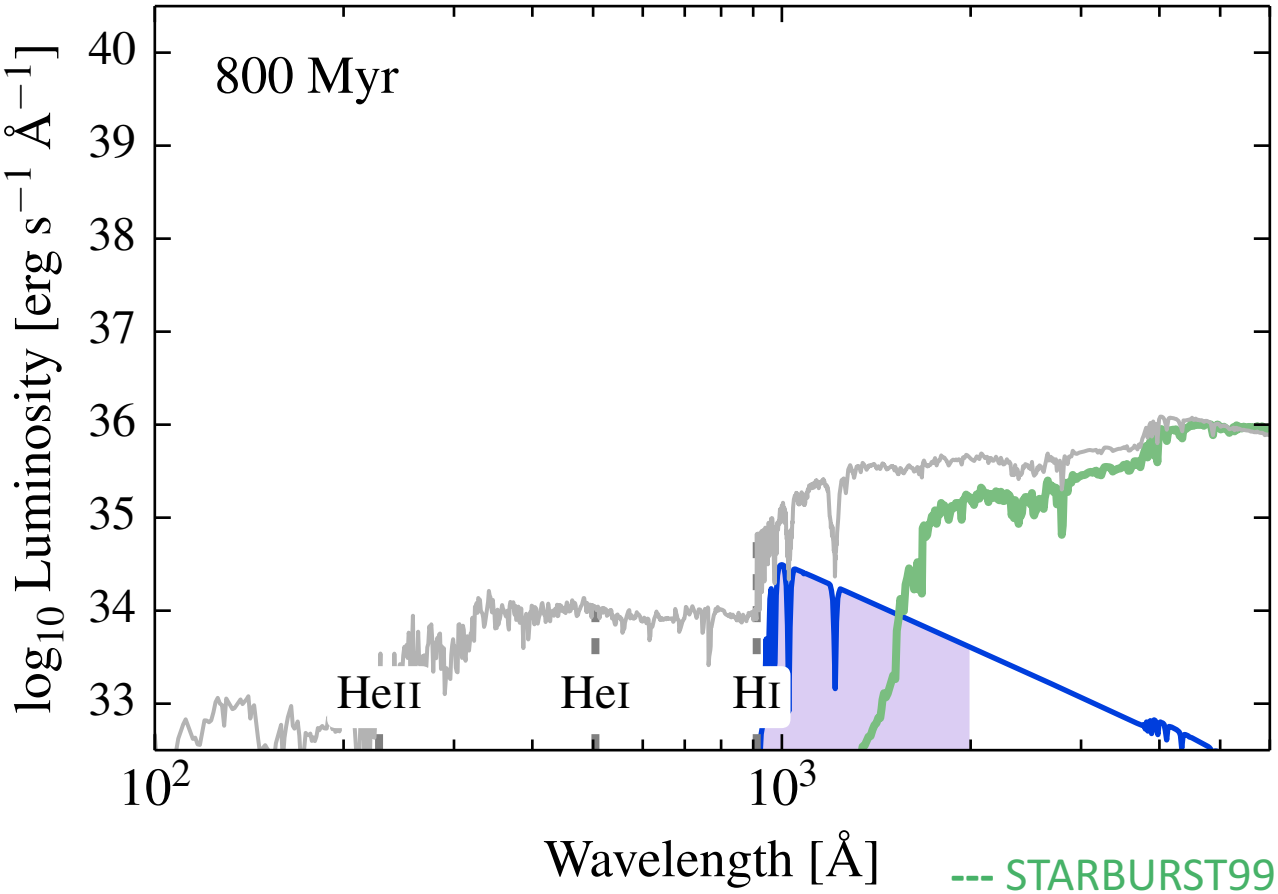
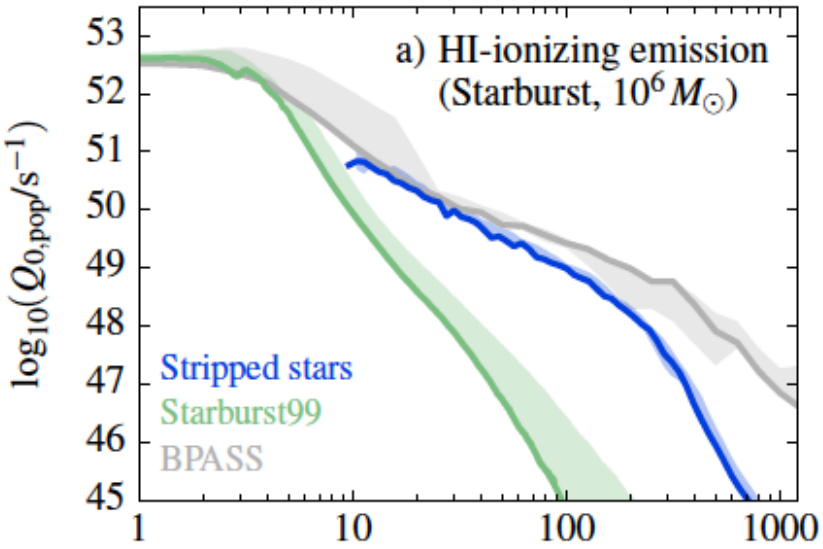
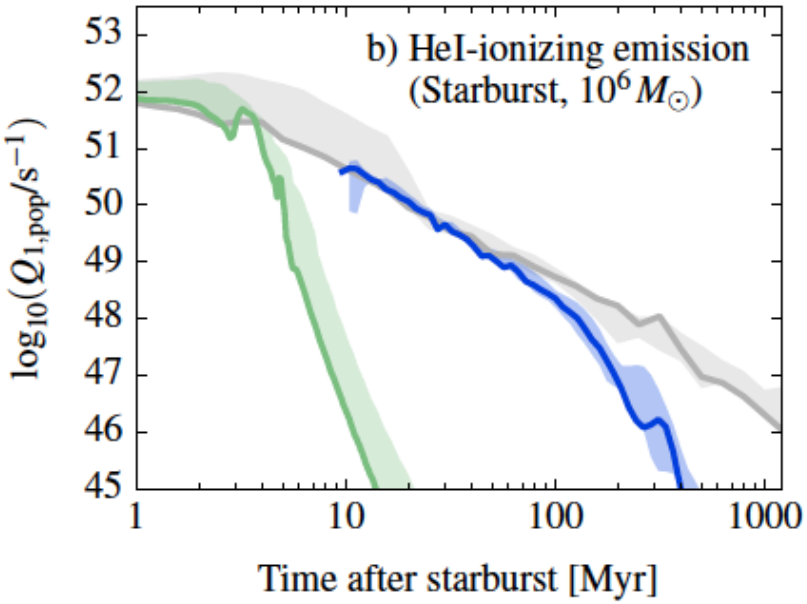


Ylva Götberg

Ionizing photons

Götberg, dM, Leitherer et al. (to be subm.)

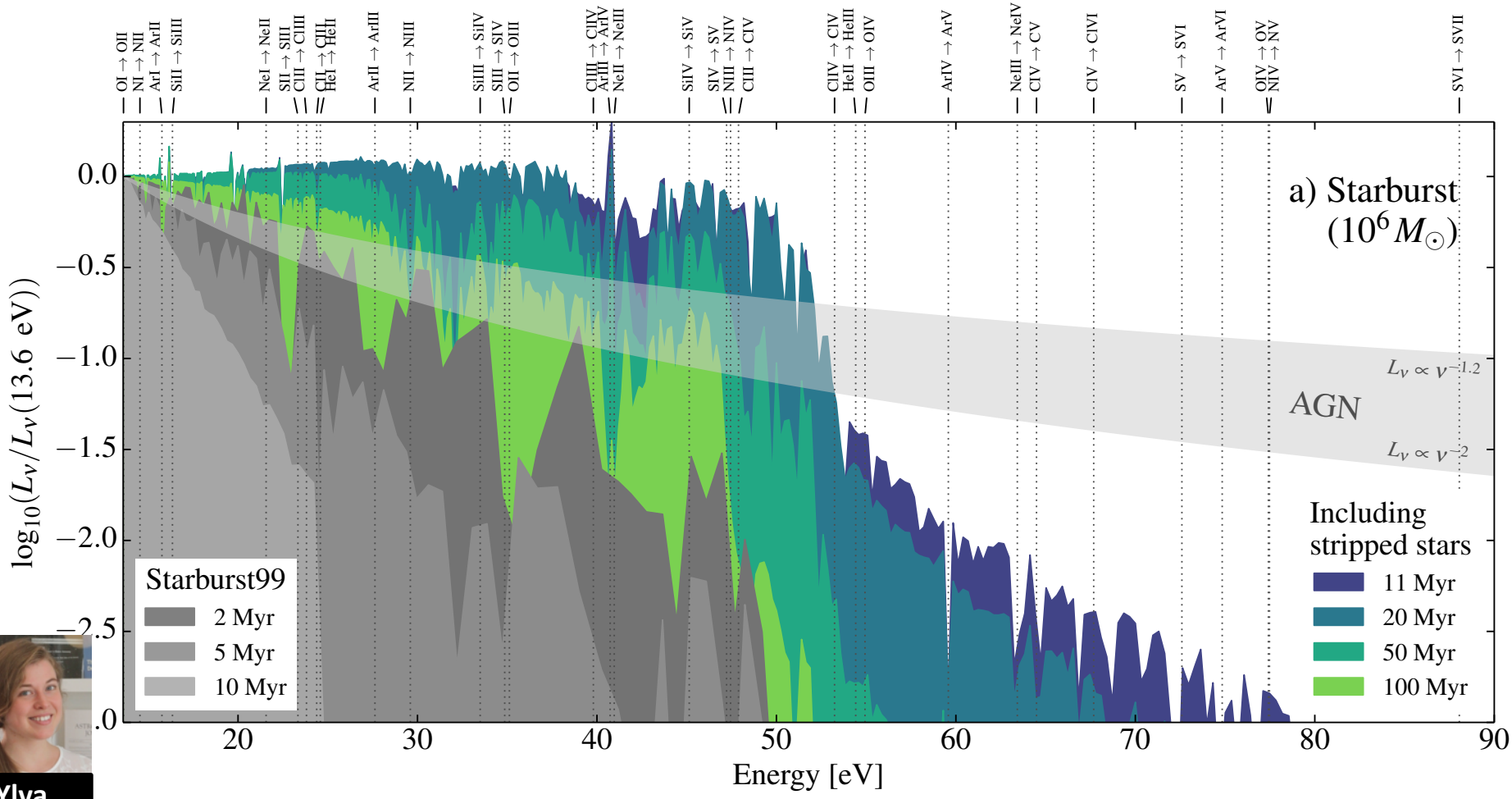


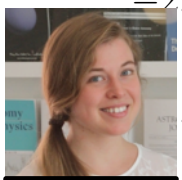


Ylva Götberg

Observable Consequences

Götberg, dM, Leitherer et al. (to be subm.)





Ylva Götberg

Possible contribution to HI - Reionization

Warning preliminary

Götberg, dM, et al. (in prep.)

Ylva Götberg

Applications / Implications

1. Ionizing photons

Götberg et al. 2017, 2018 & to be subm.

2. Late Supernovae

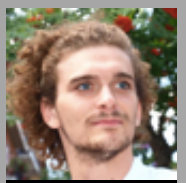
Zapartas et al. 2017, 2018 & to be subm

3. Walkaways & Runaways

Renzo et al. 2018a, b

Ylva Götberg

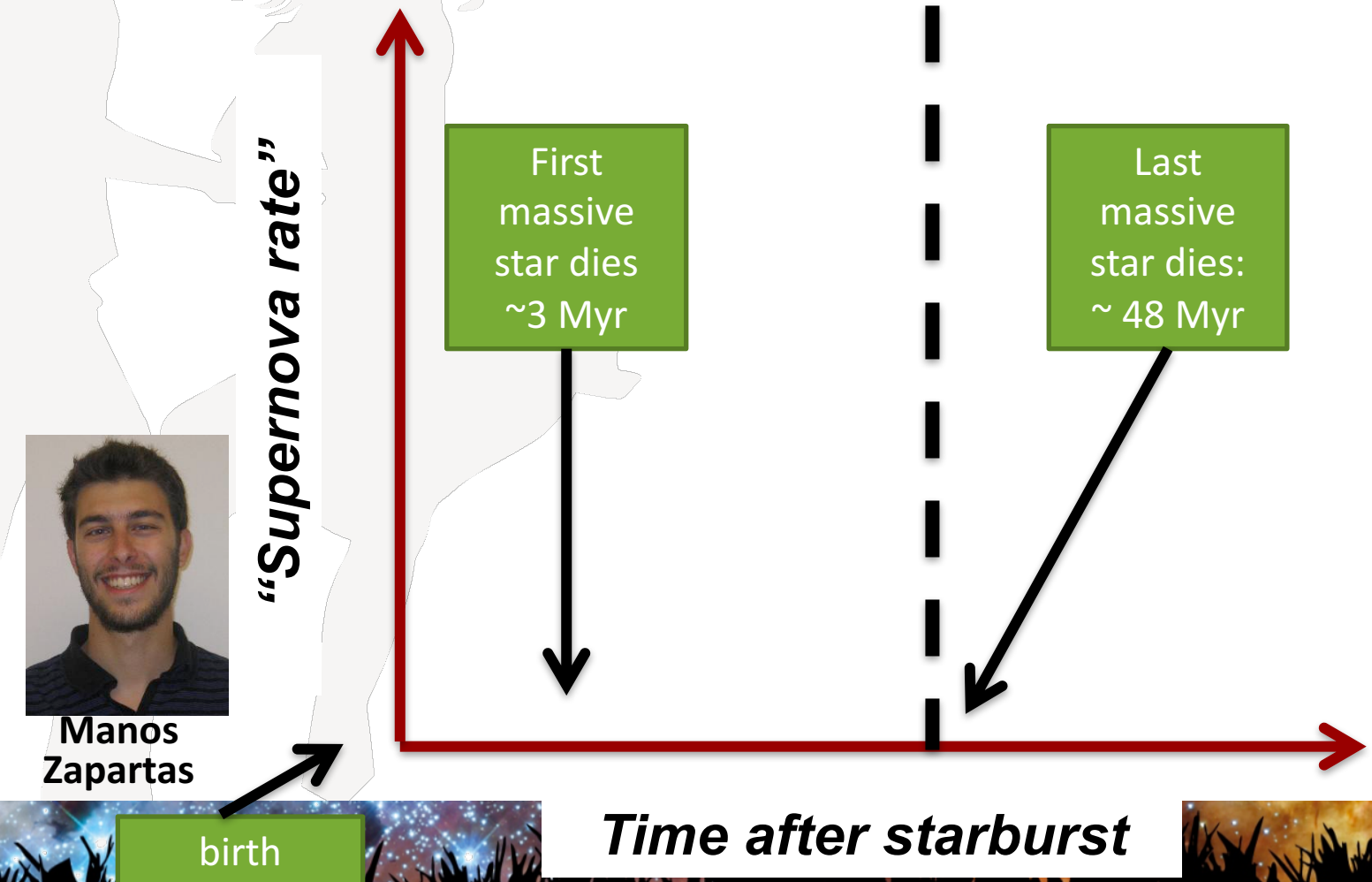
Manos Zapartas



Mathieu Renzo

I. When?

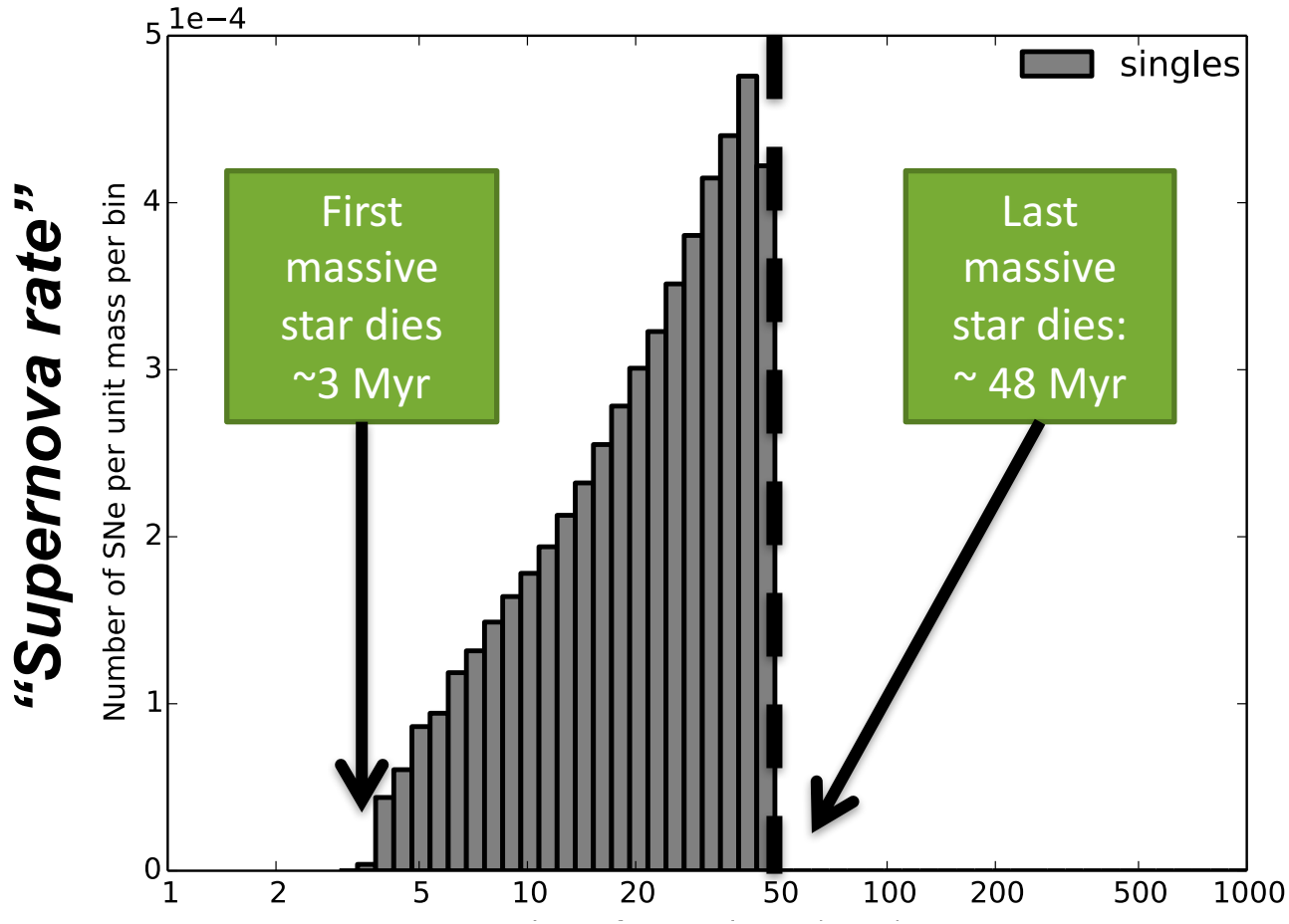
Delay time distribution:

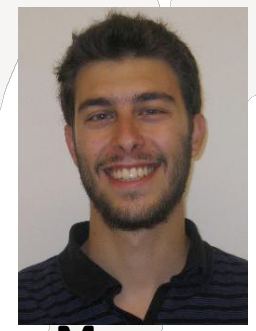


Manos Zapartas

Result for single stars

Zapartas & de Mink et al. (2017,8)



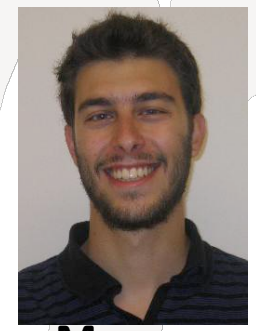


Manos Zapartas

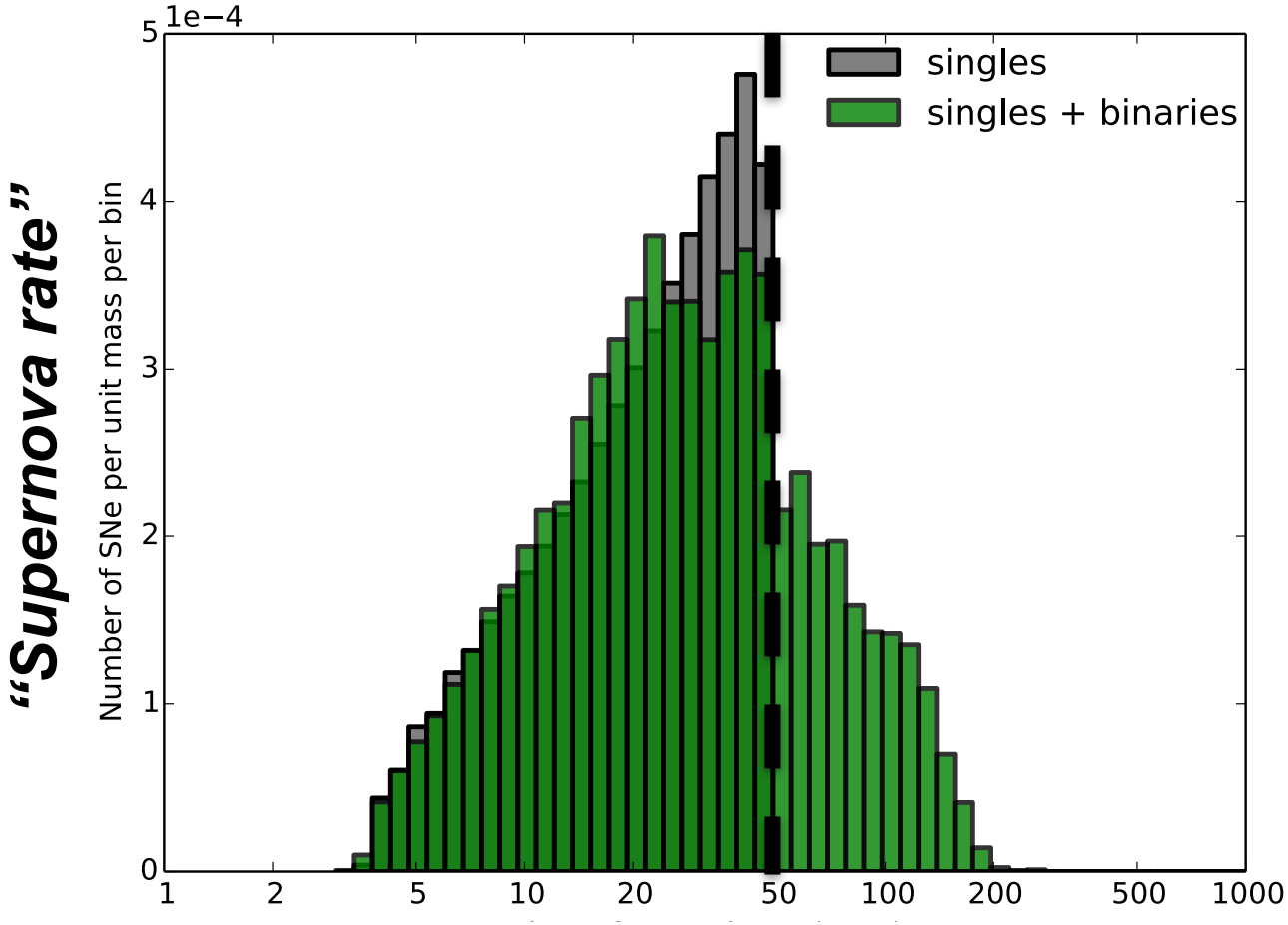
Including binaries

Compare with work by Vanbeveren+.and Eldridge+
Simulations with Rob Izzard's Binary_c code

Zapartas & de Mink et al. (2017,8)



Manos Zapartas

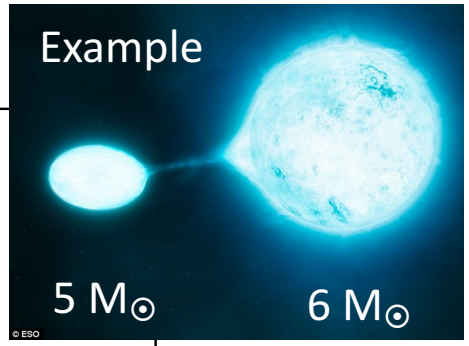


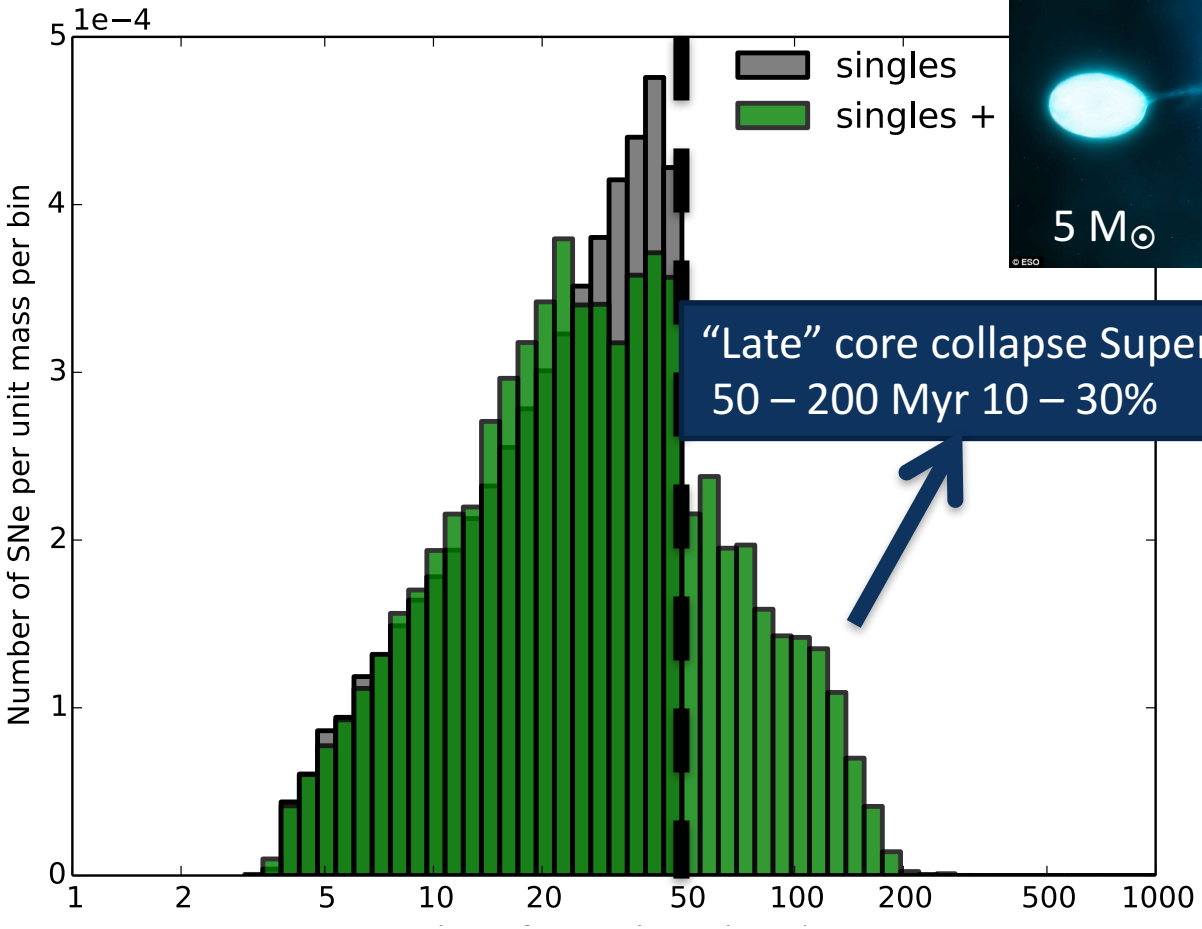
Including binaries

cf. Vanbeveren+.and Eldridge+
Simulations with Rob Izzard's Binary_c code

Zapartas & de Mink et al. (2017, 8)

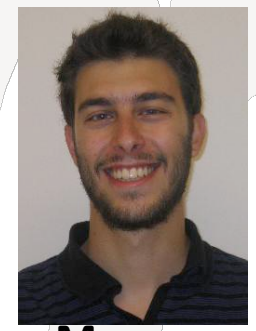
1. More supernovae: up to ~30%





"Supernova rate"

"Late" core collapse Supernovae:
50 – 200 Myr 10 – 30%



Manos Zapartas

Time after starburst

Applications / Implications

1. Ionizing photons

Götberg et al. 2017, 2018 & to be subm.

Ylva Götberg

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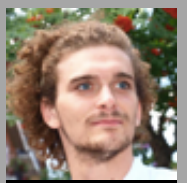
Manos Zapartas

3. Walkaways & Runaways

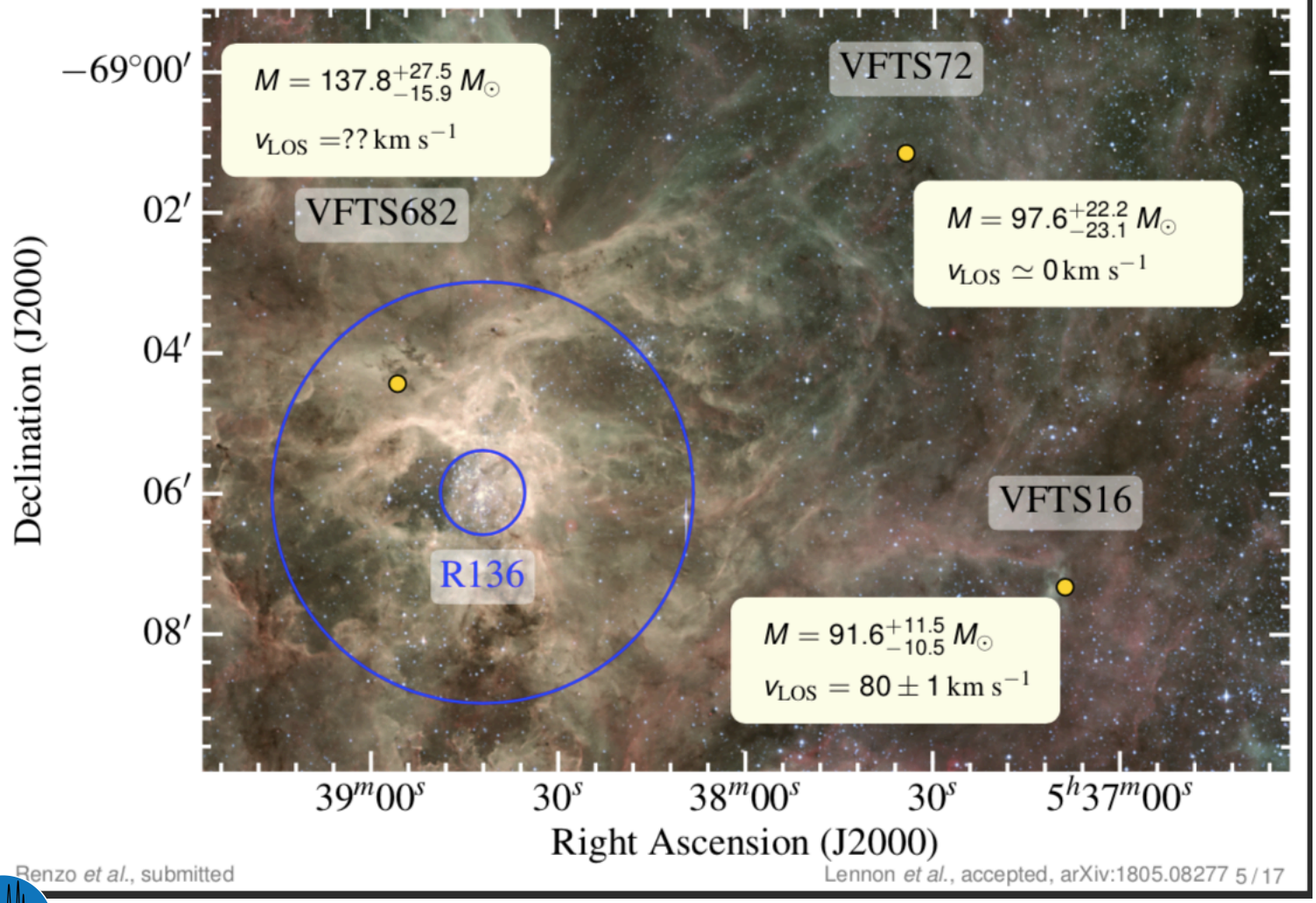
Renzo et al. 2018a, b



Mathieu Renzo

Mathieu Renzo

The most massive runaways known



Renzo *et al.*, submitted

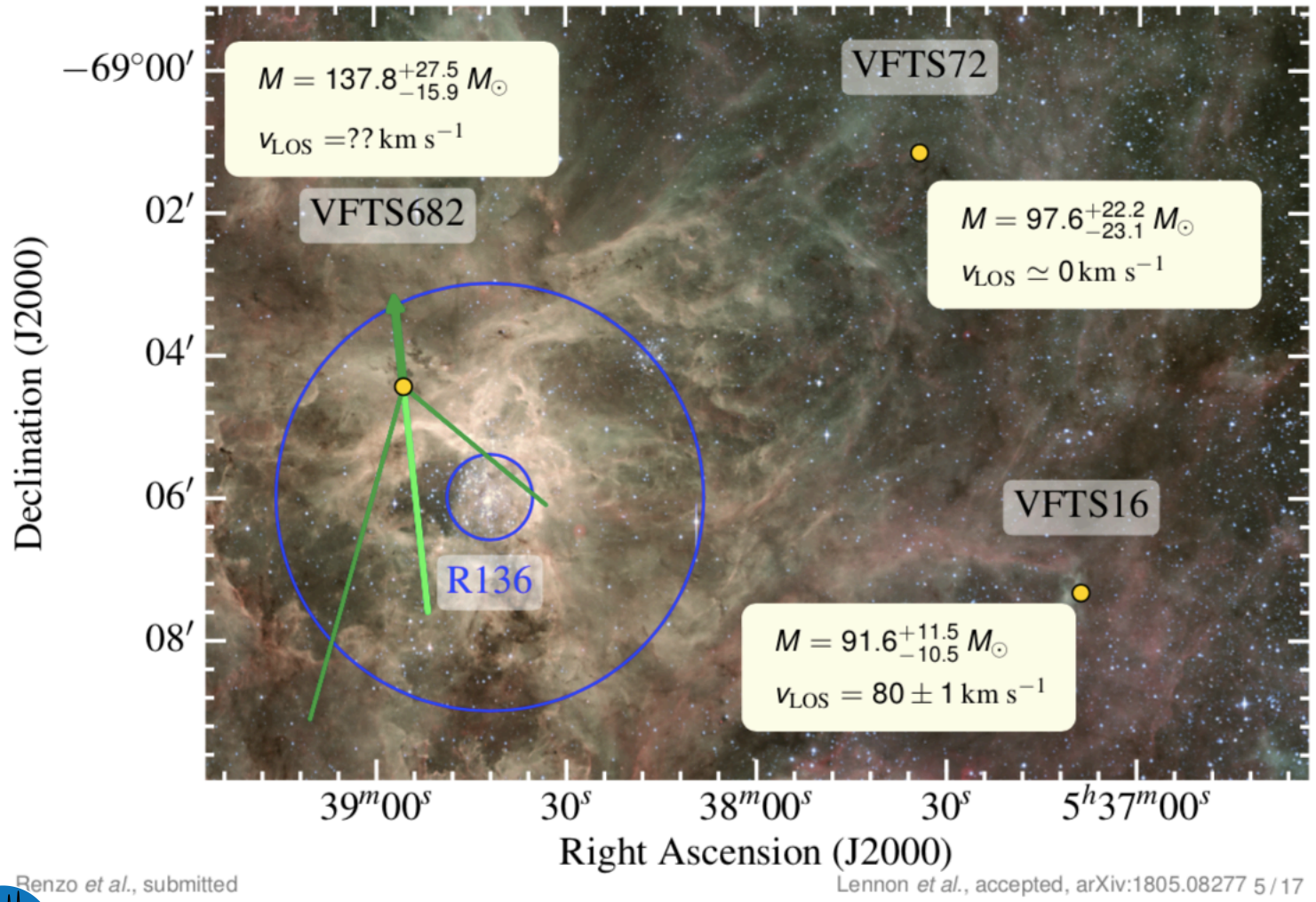
Lennon *et al.*, accepted, arXiv:1805.08277 5 / 17

Renzo et al. 2018a, b

Bin Cosmos

Mathieu Renzo

The most massive runaways known



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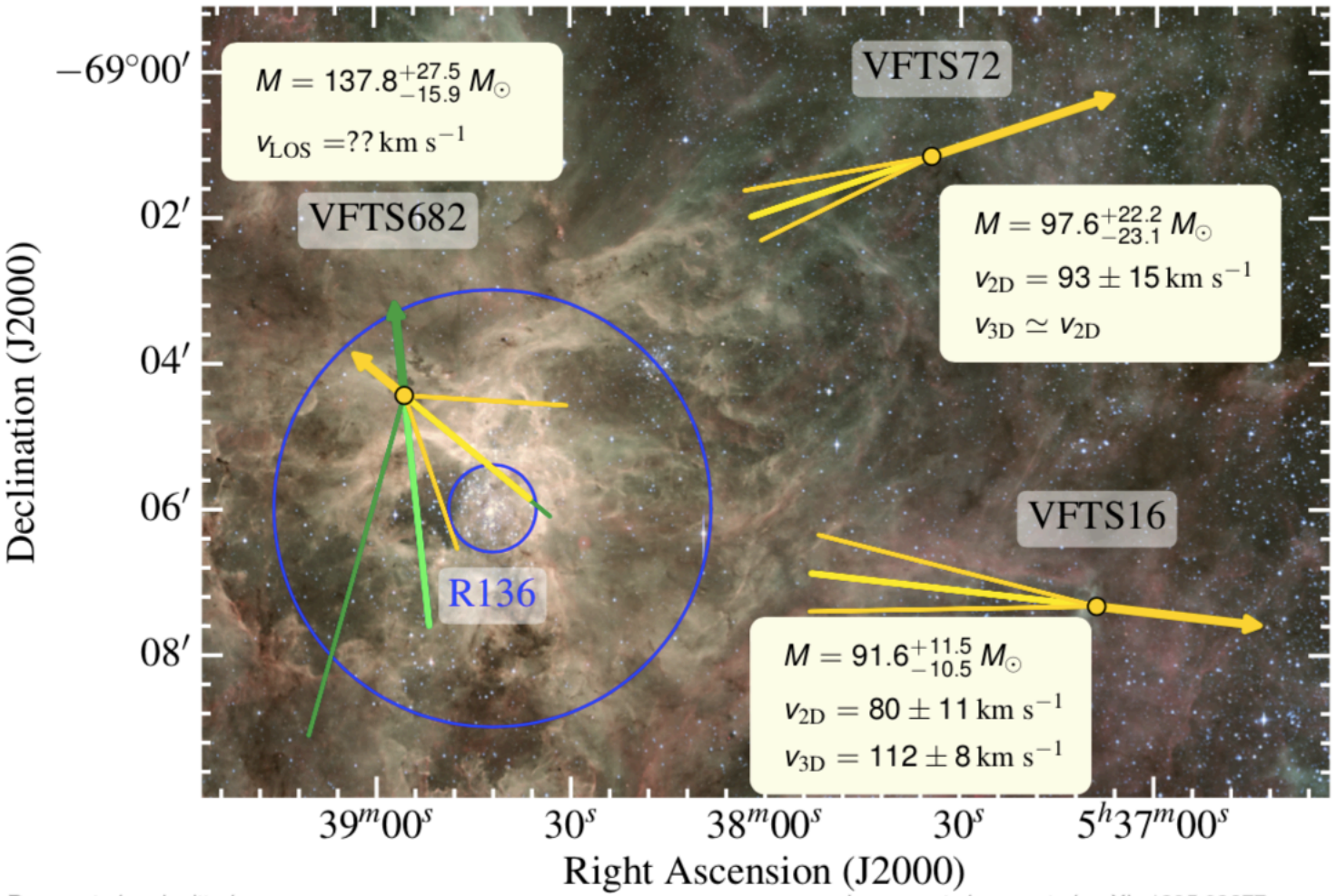

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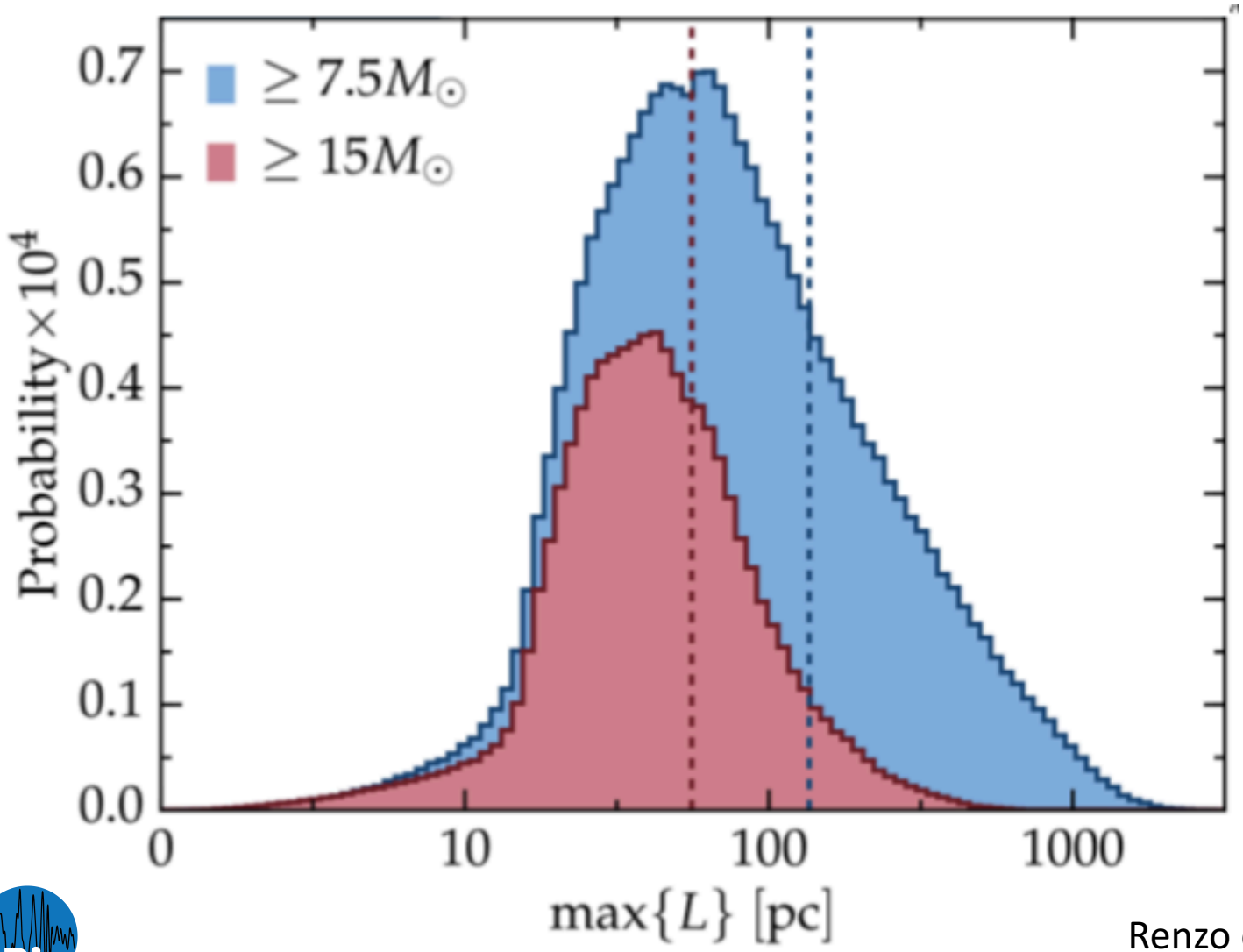
Renzo et al. 2018a, b

Bin Cosmos

Mathieu Renzo

How far do they get?

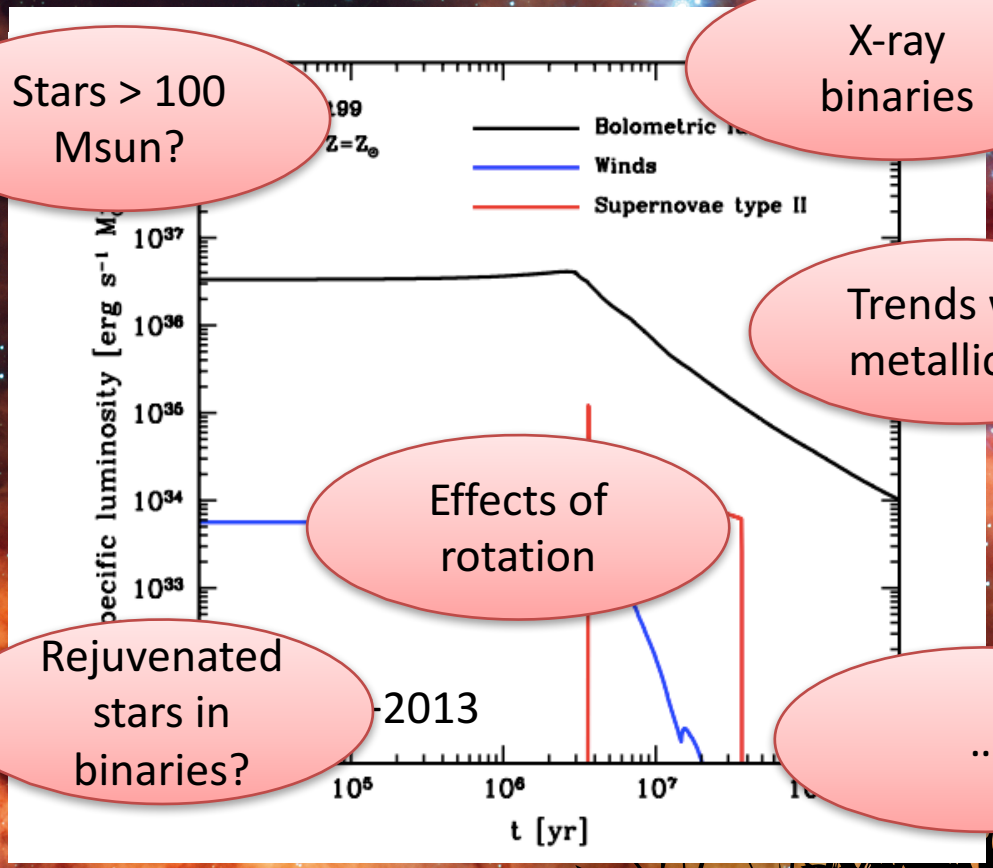


Renzo et al. 2018a, b

BinCosmos

Conclusions

How complete is this picture?



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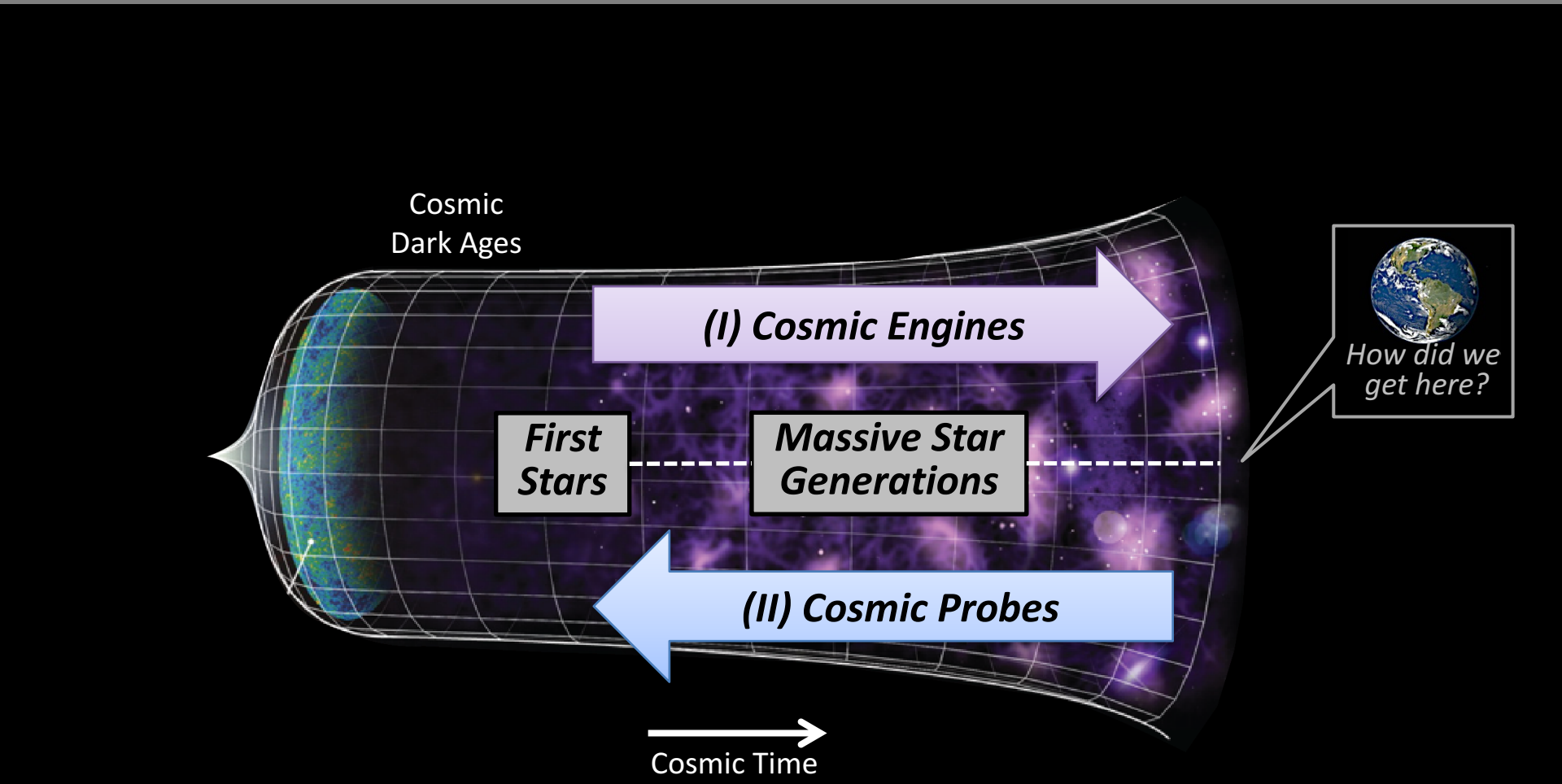
Credit background NASA Paresce., Design E. Butink


Cosmic
Dark Ages
(I) Cosmic Engines
First
Stars
Massive Star
Generations
How did we
get here?
(II) Cosmic Probes
Cosmic Time

(I) Cosmic Engines

Massive Star Generations

(II) Cosmic Probes

How did we get here?

Bin Cosmos

Acknowledging various people:
Wolfgang Kerzendorf, Jose Groh, Nathan Smith, Maria Drout, Thomas Kupfer, Sung-Chul Yoon, Carles Badenes, Ilya Mandel, Pablo Marchant, Chris Belczynski, Andrew King, Philip Podsiadlovski, Ed van den Heuvel, Simon Portegies-Zwart, Rob Izzard, Simon Stevenson, Alejandro Vigna-Gómez, Coen van Neijssel, Abel Schootemeijer, Norbert Langer, Tom Maccarone, Hugues Sana, Chris Evans, Ori Fox, Schuyler van Dyk, Claus Leitherer, Leonardo Almeida, Alex de Koter, Tony Piro, Paul Crowther, …

VLT-FLAMES Massive Star Consortium,

(I) Cosmic Engines

Massive Star Generations

(II) Cosmic Probes

How did we get here?

Bin Cosmos